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H. Zech

F. Heine

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P. M. Pimentel

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LCTS ON ALPHASAT AND SENTINEL 1A: IN ORBIT STATUS OF THE LEO TO GEO DATA RELAY SYSTEM

H. Zech[1], F. Heine[1], D. Tröndle[1], P. M. Pimentel[1], K. Panzlaff[1], M. Motzigemba[1], R. Meyer[2], S. Philipp-May[2]
[1] TESAT Spacecom, 71522 Backnang, Germany, [2] DLR, 53227 Bonn, Germany

I. INTRODUCTION

The performance of sensors for Earth Observation Missions is constantly improving. This drives the need for a reliable, high-speed data transfer capability from a Low Earth Orbit (LEO) spacecraft (S/C) to ground. In addition, for the transfer of time-critical data to ground, a low latency between data generation in orbit and data reception at the respective mission control center is of high importance. Laser communication between Satellites for high data transmission in combination with a GEO data relay system for reducing the latency time addresses these requirements.

Laser communications has been considered for space applications since the invention of the laser. The shorter wavelength in the optical regime leads to narrower beams compared to traditional radio frequency (RF) communication systems. The narrow optical beam width make optical communication the ideal candidate for point to point links. The vulnerability to link interference through a third party is drastically reduced. Jamming a coherent homodyne optical inter-satellite link is almost impossible. In addition, there are no regulations for the use of the optical spectrum, as can be found in the RF communication frequency bands. This makes the planning of the intersatellite links much easier. Another advantage of optical communication links results from the high optical carrier frequency. With this high carrier frequencies combined with the modulation capabilities in the optical regime, communication data rates in the high Gbps regime can be realized that are not possible with standard RF technology.

Since November 2007, TESAT-Spacecom (Germany) has been successfully conducting optical inter-satellite communication using Laser Communication Terminals (LCTs) built by TESAT and funded by DLR [1]. Two first generation LCTs were embarked on US NFIRE (Near-Field InfraRed Experiment) spacecraft and TerraSAR-X German commercial SAR spacecraft, with support of German Space Agency (DLR) and US Missile Defence Agency (MDA). Optical LEO-LEO inter-satellite link experiments at 5.6 Gbit/s data rate, and optical satellite-to-ground links were performed. Other experiments like the european Semiconductor Inter satellite Link EXperiment (SILEX) System have achieved optical links between LEO and GEO and from GEO to ground [2]. Only recently, in October 2013 NASA Lunar Laser Communications Demo (LLCD) has performed high datarate optical links from moon orbit to ground [3], and in June 2014 US OPALS demonstrator transmitted a video message by laser beam from ISS to ground [4].

Currently, LCTs suitable for link distances between LEO and GEO orbits are being deployed. Two units have been launched onboard Alphasat GEO-stationary spacecraft [5] in July 2013, and on Sentinel-1A LEO Earth observation spacecraft in April 2014. Further units will be embarked on Sentinel-2A/-1B/-2B and on EDRS-A/-C satellites, forming together the European Data Relay System (EDRS) [6], starting commercial service in 2015.

II. LCT DESIGN PRINCIPLES

The year 2007 saw the launch of two LEO S/Cs, both having a TESAT LCT of the first generation on board. Since then, LEO to LEO communication links and LEO to ground communication links were exercised providing a lot of knowledge on optical communication links in space [1].

In the LCT of the second generation, the LCT design of the first generation was enhanced to cover LEO to GEO distances. Table 1 shows the technical key parameters of both LCT generations.

TESAT LCTs used on Alphasat and in EDRS belong to the second generation of TESAT LCTs. Both LCT generations provide full-duplex communication by a 1064nm BPSK modulated laser beam. Beam divergence angle is as low as 10µrad, which leads to beam diameter of roughly 400m after LEO-GEO distances. This property enables “stealth” communication and provides robustness against interception by other parties.

TABLE I. LCT KEY PARAMETERS

	LCT Key Parameters	
	1[st] generation LEO to LEO	*2[nd] generation LEO to GEO*
Range	5100 km	45000 km
Data Rate	5,625 Gbps	1,8 Gbps
Data format	1064 nm, BPSK homodyne	1064nm, BPSK homodyne
Transmit Power	0,7 W	2,2 W
Telescope diameter	125 mm	135 mm
Mass	35 kg	53 kg
Power consumption	120 W max	160 W max
Dimensions	0,5 x 0,5 x 0,6 m	0,6 x 0,6 x 0,6 m

The block diagram in Figure 1 illustrates the LCT design principle. The LCT operates at 1064 nm wavelength based on Nd:YAG technology. For best sensitivity, a coherent BPSK modulation scheme was chosen applying a coherent receiver with a local oscillator laser. A bidirectional communication link operating at 1,8 Gbps user data rate in both directions is implemented. The transmit and receive path are sharing the same telescope, separation is achieved by polarization and frequency. The communication beam is also used for acquisition purposes applying a spiral scanning scheme and thus avoiding a beacon.

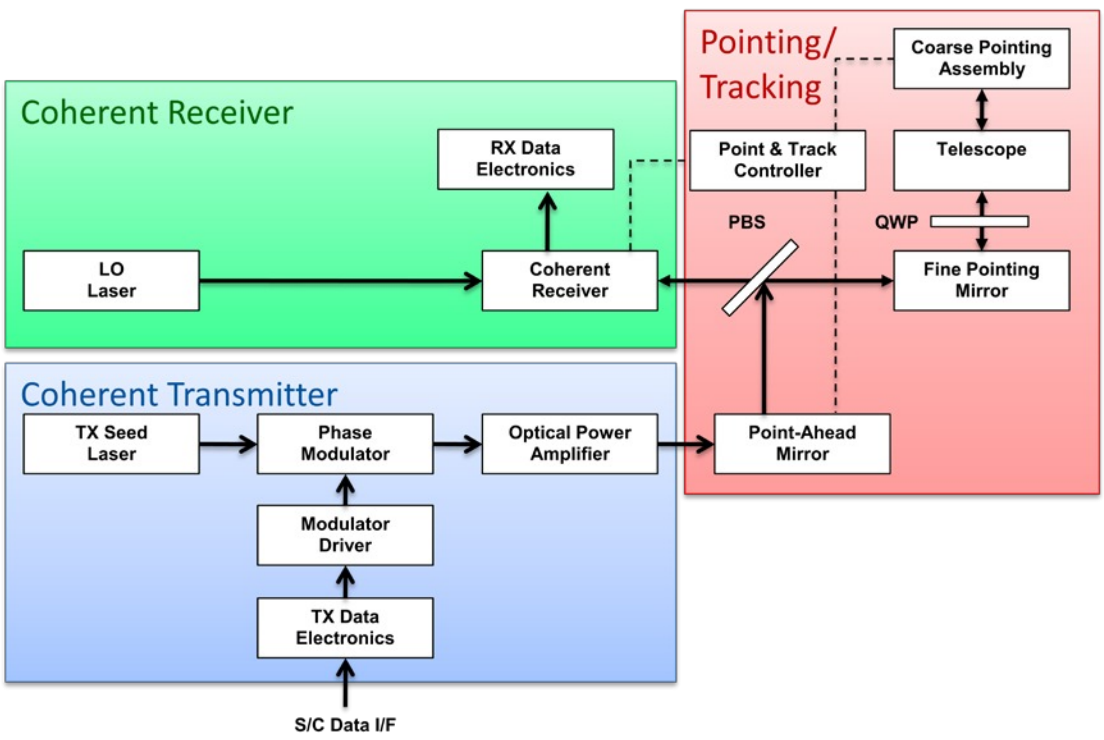

Fig. 1. LCT block diagram.

Figure 2 shows the second generation LCT with its Coarse Pointing Assembly (CPA) in unparked condition. The CPA is the major beam steering mechanism that allows beam pointing towards a complete hemisphere.

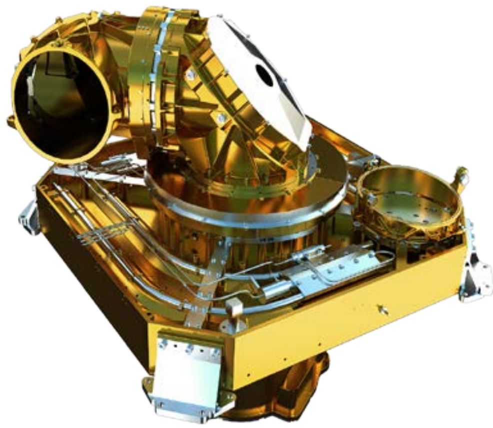

Fig. 2. 2nd generation LCT.

III. LEO GEO DATA RELAY SYSTEMS

In a LEO to GEO data relay scenario, the LEO spacecraft no longer transmits the acquired data directly to ground, but to a GEO-stationary spacecraft, which forwards the data to ground. The obvious advantage is that a LEO spacecraft has a line of sight to GEO spacecraft for almost 50% of an orbit. The GEO forwards the data to ground by a fixed RF with high data rate. The ground station can be situated at any convenient location within line of sight to GEO spacecraft, relying on available infrastructure.

Data relays fully based on RF communications have been realized with up to 300 Mbps (US TDRS). Optical data relays are using laser links instead of RF links leading to a significant performance improvement in terms of data rate. EDRS and its precursor mission Alphasat are following the Optical Data Relay approach. The EDRS LEO-GEO optical intersatellite links are operating at a data rate of up to 1.8 Gbps [6].

IV. ALPHAST TDP1 AND SENTINEL 1A LCT IN ORBIT STATUS

Alphasat, the largest European GEO-stationary telecommunication satellite, carries onboard TDP1, the world's first LEO-GEO high-speed data relay system. TDP1 consists of a Laser Communication Terminal to receive the user data from its counterpart on a LEO spacecraft, and a Ka-Band RF transmitter to forward the received data to DLR DFD ground station in Oberpfaffenhofen, Germany.

During in-orbit commissioning of Alphasat TDP1, laser links were performed between the LCT and the ESA optical ground station La Teide at Tenerife, the Canary Islands, Spain. A first link campaign was performed in March 2014. The goal of the campaign was to execute the laser beam pointing, the automatic acquisition routine and the transition to coherent link tracking of Alphasat TDP1. Details of the campaign are given in [7]. The key findings are summarized in the following.

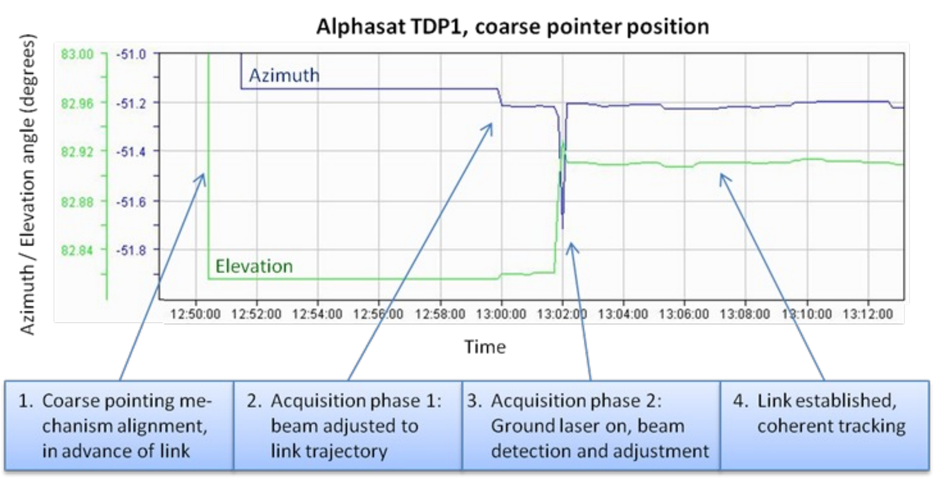

Fig 3: beam steering mechanism position during link acquisition

Fig.3 shows a typical movement of the in orbit LCTs 2-axis Coarse Pointing gimbal mechanism during an acquisition phase. Prior to start of link, the 2-axis LCT Coarse Pointing gimbal mechanism was commanded to the initial link position. At the start of the link, Alphasat TDP1 LCT was set as master terminal and performing spiral scans with its laser beam fine pointing mirrors in the direction towards the optical ground station (OGS). This first phase lasted 120 seconds, during which the OGS was manually aligned to the center of the flashing signal. After alignment, the 10W ground laser was activated towards the TDP1 LCT as phase 2 acquisition started.

Now using its acquisition sensors and fine-steering mirrors, the Alphasat LCT aligned its optics to the OGS uplink beam and fulfilled the transition from coarse to fine acquisition. After both link partners were sufficiently aligned to each other, the signal was received by the LCT’s four quadrant coherent detector and the LCT changed from acquisition phase to coherent tracking mode, keeping itself actively aligned onto the incoming laser beam from now on. During the described optical ground links, strong scintillation effects due to atmosphere and clouds were observed, causing deep signal fades. Yet, stable tracking was achieved even at RX intensities of less than 10% of the lowest specified RX intensity during a LEO-GEO link (Fig. 4).

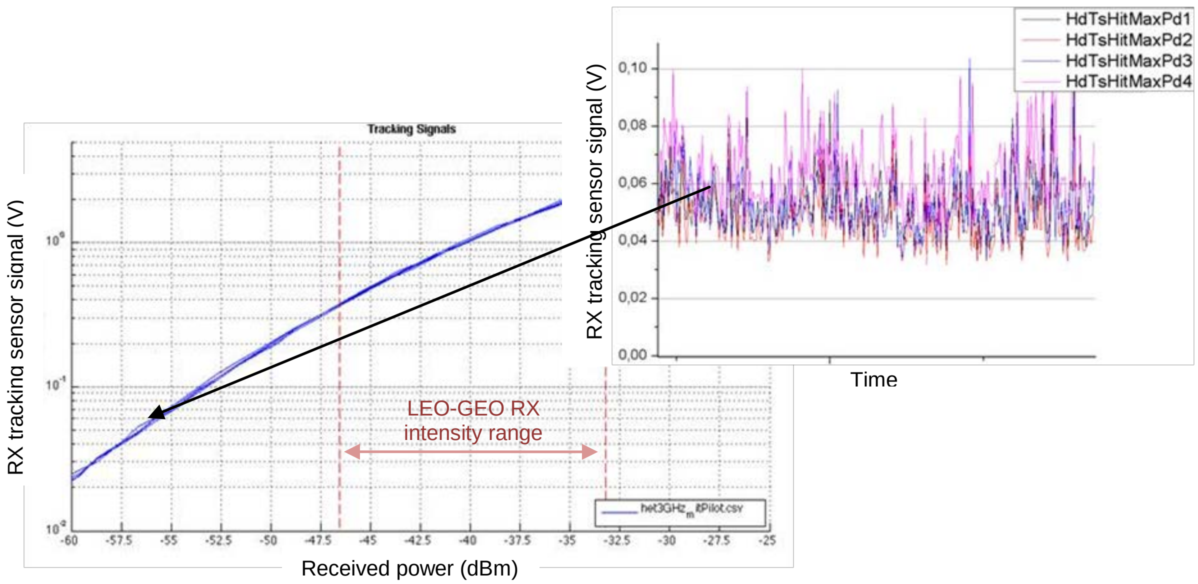

Fig 4: Coherent tracking at GEO-ground RX signal strength (inlay), much below LEO-GEO RX intensity

Only at much lower tracking sensor level, when thick clouds interrupted the link, tracking was lost. In this case, the LCT automatically re-started the link acquisition by spiral scanning, resuming tracking as soon as clouds were passed. This was demonstrated for a high number of cycles.

In conclusion, the LCTs algorithms for spatial acquisition based on spiral scanning, the autonomous transition from spacial acquisition to tracking, and tracking under severe atmospherical conditions was demonstrated successfully between Alphasat as a GEO S/C and the ESA optical ground station located in Tenerife.

The first LEO S/C having an LCT of the second generation on board, is Sentinel 1A, see Fig. 5. The Sentinel 1A LEO S/C is foreseen to be the first LEO S/C customer for EDRS. Sentinel 1A was launched in April 2014, the in orbit commissioning phase is ongoing. The Sentinel 1A LCT was switched on and its interfaces to the S/C verified. LCT internal selftests have been executed successfully. This includes optical selftests that make use of the complete optical transmit and receive path of the LCT, by means of LCT internal reflectors.

With these selftests passed successfully, the Sentinel 1A LCT is ready for the LEO to GEO optical intersatellite links. LEO to GEO optical intersatellite links between the LCTs on Sentinel 1A and Alphasat are foreseen later in 2014.

Fig. 5. LCT integrated on Sentinel 1A S/C, (picture courtesy of TAS-I).

V. CONCLUSION

Alphasat TDP1 Laser Communication Terminal as the first high-speed optical LEO-GEO relay and the precursor for the European Data Relay Satellite System has been delivered to orbit and successfully demonstrated the pointing, acquisition and coherent tracking phases of a laser link to an optical ground station. Stable tracking even during thin layers of clouds with RX signal intensity much lower than for LEO-GEO-links confirm the robustness of the system architecture. Sentinel 1A, launched in April 2014, has the counterpart LEO LCT on board. The Sentinel 1A LCT passed the first in orbit commissioning phase successfully. Both LCTs are ready to perform LEO to GEO optical intersatellite link.

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